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Comparison between conventional and vegetated roof by means of a dynamic simulation

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Abstract

In this paper, a dynamic simulation of a building located in the Campus University of Palermo, Italy, has been carried out. We considered two different scenarios; in the first one, the building as it is, with a conventional covering, while in the second one the roof was equipped with a green roof. The results of the two simulations have been compared, suggesting that such building component could contribute to the energy savings of the building. However, it has to be considered as part of other possible actions devoted to improve the energy efficiency of the whole building.

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Keywords: green roofs; energy building simulation; energy savings; green roof model; energy performance of buildings.

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1. **Introduction**

Green roofs are considered to be an effective solution to improve internal and external environment at the building and urban levels. In comparison to conventional roofs, green roofs present many benefits, such as reducing the air pollution, mitigating noise, improving the management of runoff water, increasing the urban biodiversity, and the reducing the energy consumption of buildings, especially for cooling purposes [1-5]. Berardi et al. [6] report a state-of-the-art analysis of the environmental benefits of green roofs. There is a growing literature data regarding the energy benefits of green roofs [5], even if a comprehensive assessment in quantitative terms is still a challenge [7]. The thermal performance of green roofs is generally evaluated by means of modeling simulation or numerical

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estimation using the involved parameters, which are collected experimentally or from databases [8-14]. Moreover, the thermal transmittance coefficient usually is estimated in steady state numerical approaches that utilised suitable data-loggers; a steady state numerical calculation of the thermal transmittance coefficient has a very restricted range of applicability [14]. As regard the importance of vegetation in the simulation process, Lazzarin et al. [10] tuned their model in TRNSYS software to stress the significance of plant evapotranspiration, while Sailor [13] combined a model based on the Army Corps of Engineers (FASST) vegetation model [15] with the Energy Plus simulation program.

In this paper, a dynamic simulation of a building located in the Campus University of Palermo, Italy, has been carried out. We considered two different scenarios; in the first one, we considered the building as it is, with a conventional covering, while in the second one the roof was equipped with a green roof. The results of the two simulations has been compared in terms of energy savings and comfort of inhabitants.

2. Green roof components

In Italy, green roofs are not very common yet, even if they are starting to spread. The issue of the Italian standard UNI 11235:2007 “Instructions for the design, execution, control and maintenance of green roofs” (Istruzioni per la progettazione, l’esecuzione, il controllo e la manutenzione di coperture verdi) [16], that defines planning, realization, control and maintenance criteria of a green covering, has leaded to the commercialization of several ready-to-install packets, promoting the use of such innovative building components.

The layers composing a green covering, as reported in the UNI 11235:2007, are the following from bottom to top:

- Structural layer, supporting the loads;
- waterproof layer, protecting the roof from water infiltration, generally made of a bituminous or PVC membrane;
- root barrier layer, protecting the insulation from the root, often coupled with the previous element by treating the membrane with suitable chemical agents;
- protection mat, protecting the root barrier from mechanical damage;
- drainage layer, draining surplus water from the roof;
- moisture retention layer. Accumulating meteorological or irrigation water for dry periods;
- filter fabric layer, protecting the drainage layer from thin particles;
- growing medium, generally a lightened soil containing peat, pumice, lapillus, bark and natural fibres;
- plant layer.

There are mainly two types of green roof: intensive and extensive. The first type is characterized by thin growing medium (8-15 cm) and vegetal species that can adapt themselves to the local environmental conditions (sedum, herbs and shrubs), while the second one has a thicker growing medium (until 1 m) and with all kind of vegetal species (from shrubs to trees). The two types of coverings, obviously, strongly differ in both installation costs and maintenance.

3. Dynamic simulation model

The available green-roof models for energy simulation programs are increasing in literature. They differ among them for being simplified or complicated mathematical model of heat and mass transfer, assuming the thermal properties of green roof constant or affected by latent heat and by water content [17-18], being one-dimensional or multi-dimensional model, having a higher or lower degree of detail.

In any way, the main programs utilized for building energy simulation currently not allow to choose among different mathematical models for green roof, at the very most they contain a mathematical model. This is the case of EnergyPlus program that is one of the newest and advanced software for building energy simulation.

The green roof model implemented in EnergyPlus program is based on the Fast All-season Soil Strength (FASST) model developed by Frankenstein and Koenig [15] and with some modifications introduced by Sailor [13].

As is obvious, the energy balance of a green roof is dominated by solar irradiance, and this is balanced by sensible and latent heat flux from soil and canopy with heat conduction into the soil substrate and long-wave radiation to and from leaf and soil [13] (see Fig.1). In other word, the energy balance of the green roof model takes into account: a) canopy effects on convective heat transfer; b) evapotranspiration from the soil and plants; c) heat conduction in the soil layer; d) longwave and shortwave radiative exchange.

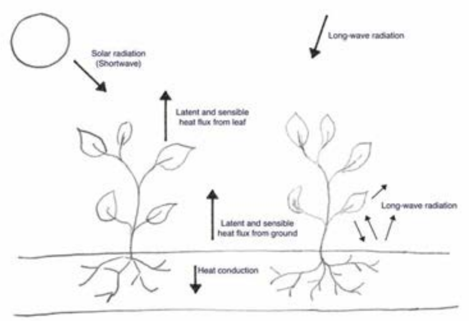

Fig. 1. Sketch of the energy balance of a green roof.

Moreover, the green roof model of EnergyPlus program includes a simplified moisture balance as well as soil surface and foliage temperature equations that are solved simultaneously. The model assumes the thermal properties of green roof not affected by moisture and does not take into account the effects of the drainage layer.

As its interface is not easy to use, a more user-friendly software has been used, namely Design Builder [19]. Green roofs can be modeled in Design Builder by creating a roof construction using a Green roof material as the outer layer.

The main input parameters of the green roof model are [20]:

- Height of plants;
- Leaf area index (LAI);
- Leaf reflectivity;
- Leaf emissivity;
- Minimum stomatal resistance;
- Max volumetric moisture content of the soil layer (saturation);
- Min (residual) volumetric moisture content of the soil layer;
- Initial volumetric moisture content of the soil layer.

4. A case study

The analysed building is located in Palermo (Lat. 38° 06' N, Long. 12° 56' E, elevation 60 m a.s.l.). It is a situated inside the Campus of the University of Palermo and identified as “Building 9”, namely the Dipartimento di Energia, ingegneria dell’Informazione e modelli Matematici (DEIM).

4.1.Building description

The analysed building has four floors and a basement floor (Fig. 2-right). The latter is composed of laboratories and technical rooms with ceiling height equal to 3.5 m. The first floor consists of the main entrance of the building and laboratories. In this floor, the ceiling height is equal to 4.20 m. The second and third floors consist of office spaces with ceiling height of 4.20 m. Finally, the fourth floor houses a solar laboratory and a terrace on which the green roof is installed.

The building has a framed structure with infill walls made of tuff bricks and a flat roof consisting of concrete and bricks and windows are double glass with air (4-12-4) with aluminium frame. The main thermo-physical properties are for: a) outer walls thickness 36 cm and trasmittance 2.635 (W m^{-2} K^{-1}); b) glass type 4-12-4 and trasmittance

2.725 (W m^{-2} K^{-1}); c) roof thickness 32.5 cm and trasmittance 1.756 (W m^{-2} K^{-1}); d) green roof thickness 53 cm and trasmittance 0.363 (W m^{-2} K^{-1}).

In two different areas of the roof (see Fig. 2) will be installed a green covering using a commercial patented Italian system, i.e. Perligarden-Perliroof® by Perlite Italiana srl [21]. Such system is suitable for the realization of intensive and extensive green coverings and hanging gardens with low thickness and weight.

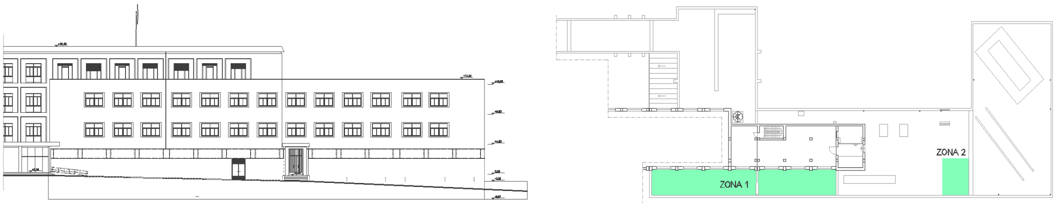

Fig. 2. The front view (left) of Building 9 and the two zones (right) on the terrace selected for the installation of a green covering.

In the following, the different layers constituting the green roof, from the outer to the inner one, are reported:

- Vegetation layer, i.e. *Phyla nodiflora* in zone 1 and *Gazania nivea* in zone 2;
- Growing medium layer AgriTERRAM® TVS, particularly indicated for extensive green coverings, a mix of inorganic inert components and organic (like clays and fertilizers) ones, characterized by slow releasing;
- Filter layer Drenalit® F130, a non-woven geotextile in calandered polypropylene;
- Water storage layer, consists of a 5 cm pillow made of a particular calandered not woven polyester geotextile, filled with inert soil of expanded perlite (Igroperlite® Agrilit T2) characterized by a granulometry of 1÷3 mm;
- Drainage layer Ecodren SD5®, a geo-composite that consists of a geo-net heat bonded to a non-woven geotextile 4.5 mm thick;
- Anti-root barrier 5 mm thick;
- Structural support consisting of a 10 cm light concrete layer, a 20 cm concrete slab and a 2 cm plaster layer.

4.2.Climatic and equipment input data model

As input for the simulation in Design Builder, the TRY of Palermo [22-23] developed by means of the Hall *et al.* method [24], has been used.

The other inputs refer to the dimension and materials of the elements and the scheduling of equipment and plants. The building is occupied during working days (Monday to Friday) from 8 a.m. to 6 p.m. Openings are double glass with air (4-12-4) with aluminium frame and inner blinds. Blinds are open from April to September on working days and closed otherwise. Lighting is provided with fluorescence lamps of various power, scheduled on from October to November (from 2 p.m. to 6 p.m.) and December to March (from 8 a.m. to 6 p.m.), while from April to September natural lighting is high enough to maintain comfort. The heating system is a mix of radiators and fan coils and is scheduled on from 7 a.m. to 12 a.m. and from 3 p.m. to 6 p.m. during the heating season. A heating (20 °C) and cooling (25 °C) setpoints are fixed. Finally, we considered a natural ventilation of nearly 0.4 ac/h for zone 2 and a mechanical ventilation for zone 2 with mean values of 1.3 ac/h in heating season and 2.8 ac/h in cooling season.

5. Results and discussions

Two different simulations have been carried out on the considered building, i.e. as it is and with a green covering, as described in the previous section, installed on top of it in the above-mentioned two zones.

Simulation results are reported in Figures 3 and 4. We report, for both zone 1 and zone 2, the comparison in terms of energy lost from roof and the total energy lost between the two described configurations.

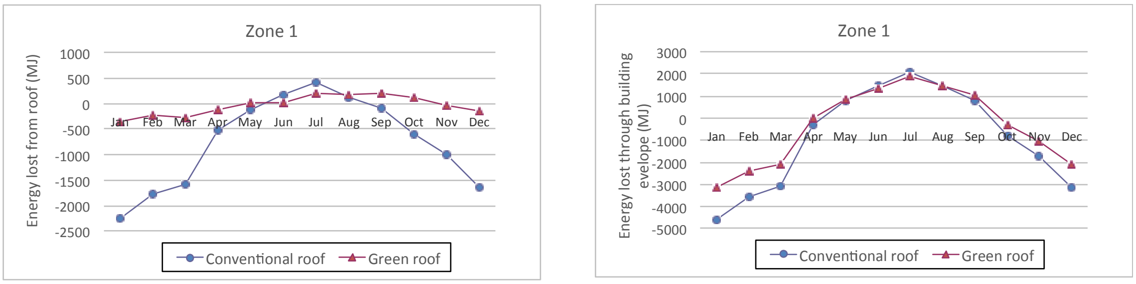

Fig. 3. Energy lost from roof (left) and through building envelope (right) for zone 1.

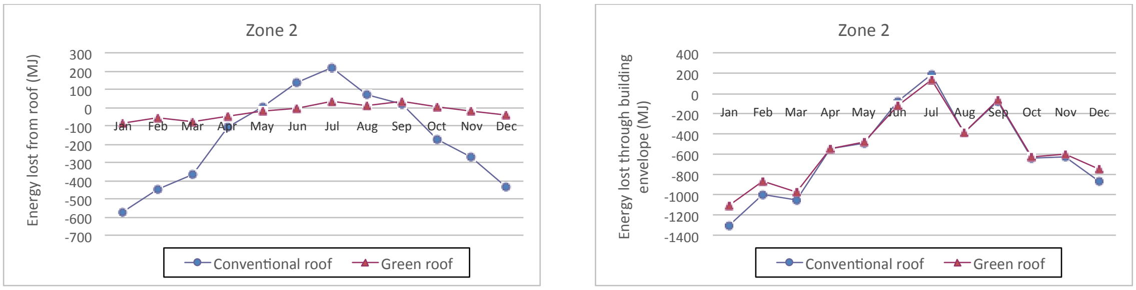

Fig. 4. Energy lost from roof (left) and through building envelope (right) for zone 2.

In Table 1, the obtainable energy savings by means of the installation of a green roof with respect to a conventional one both for heating (from December to March) and cooling (from June to August) season is reported.

Table 1. Obtainable energy savings by means of a green roof

Zone	Season	Energy savings from roof (%)	Energy savings through building envelope* (%)
Zone 1	Heating season	86.5	32.9
	Cooling season	44.7	6.0
Zone 2	Heating season	86.2	35.4
	Cooling season	89.5	29.4

*Considering only heat losses from glazing, outer walls and roof.

The simulation results refer only to the rooms under the two analyzed zones. The graphs in Figures 3 and 4 outline a greater energy savings during the heating season than in cooling season. This is also due to the limits of the used model that totally disregard the influence of moisture on the thermal properties of the green roof.

The heat flux through the roof falls into the range reported by Chen *et al.* (60-90%) [17], except for zone 1 in the cooling season. This is probably due to the big value of the ventilation rate, as reports in the previous section. The energy saving in the rooms under the two zones instead is less than the values reported by Spala *et al.* (58-73%) [3]. Moreover, zone 1 shows an energy saving percentage very low. This is probably due to the same reason above mentioned.

6. Conclusions

In the present work, we analyzed the energy saving contribution of a green roof compared with a conventional one in the city of Palermo. In fact, the contribution of the green roof depends on the climate of the installation site.

Moreover, this is the first simulation performed in order to compare the data obtained by the simulation with the actual data obtained by the monitoring of a green roof currently installed on the roof of the building. The results obtained by the simulations point out a good rate of energy saving; therefore, the green roof falls in the set of possible interventions to improve the energy performance of buildings. By the way, such energy saving greatly decreases when the ventilation rate is high.

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